Amendments to the Drawings:

Attached is New Sheet 10 to overcome Examiner's objection and Replacement Sheets 1 through 9 to indicate the numbering change.

Attachments:
  Replacement Sheets 1 through 9
  New Sheet 10

REMARKS

Drawings

The Examiner has objected to the drawings on the ground that "a pair of mutually perpendicular stripline conductors" as recited in claim 7 is not shown in any of the drawings. In response, Applicants are submitting herewith a proposed new drawing, designated FIG. 16, which is to be appended to the figures currently in the application. The Examiner's approval of the new drawing is respectfully solicited.

The Specification is being amended to include a reference to the new drawing.

Amendment to Specification

The Specification has been amended by adding a statement to the Brief Description of the Drawing to the effect that FIG. 16 (newly added) shows an embodiment of the invention including a pair of mutually perpendicular stripline conductors, and by adding a reference to FIG. 16 to the Detailed Description. Applicants submit that no new matter is added thereby.

The Current Claim Amendments

Claim 1 has been amended by adding the limitation that at least two mutually adjacent plates must contain mutually aligned apertures, one of which is at least twice the diameter of the other. This amendment is supported by the Specification at page 8, lines 20-23.

Claim 10 has been rewritten in independent form.

Claim Objections

The Examiner has objected to claim 10 as being of improper dependent form. In response, Applicants have rewritten claim 10 in independent form.

Claim Rejections under 35 USC 102(b)

(1) Claim 1, together with its dependent claims 6-7 and 9, stands rejected as anticipated by Rammos, EP0252779 ("Rammos"). Applicants respectfully traverse this rejection for the reasons set out below.

An English translation of Rammos was obtained from a commercial translation service and is attached hereto as an appendix. Citation to the Rammos text will be made to the French original, followed by point citation to the attached appendix.

Rammos is directed to an assembly of perforated metal plates in which mutually aligned apertures lying in adjacent plates are equal in diameter, or at most have "slightly different" diameters. In this regard, see Rammos, column 7, line 47, to column 8, line 1 (Appendix, page 6, lines 6-11): "The cavities . . . of the same pair . . . can have equal diameters. However, it is preferable that the diameters of the cavities of the same pair are slightly different so as to improve the bandwidth."

By contrast, claim 1 of the present application, as currently amended, includes the limitation that at least two mutually adjacent plates must contain mutually aligned apertures, one of which is at least twice the diameter of the other. It is respectfully submitted that Rammos fails to teach any such feature—i.e., a substantial difference in diameter from one aperture to the other.

As quoted above, Rammos does teach that a slight difference in diameter may advantageously increase the bandwidth. However, because the Rammos reference focuses on slight differences, it fails to motivate the use of apertures that differ in size by a substantial amount such as a factor of two or more. If anything, it teaches away from such substantially dissimilar apertures.

Thus, Applicants respectfully submit that claim 1 as currently amended is neither anticipated by Rammos under 35 USC 102, nor obvious over Rammos under 35 USC 103. For substantially the same reasons as set out above, Applicants submit further that claims 2-9 as depending from claim 1, and claim

10, as incorporating the limitations of claim 1, are likewise novel and non-obvious over Rammos.

(2) Claims 1, 2, and 10 stand rejected as anticipated by Smith et al., U.S. Patent No. 6175333 ("Smith"). Applicants respectfully traverse this rejection for the reasons set out below.

Smith describes a basic structural unit, referred to as a "triplate", in which a stripline conductor is sandwiched between two plates perforated with corresponding, mutually aligned apertures. Significantly, Smith teaches that within a given triplate, the mutually aligned apertures should have the same diameter, so that each triplate will operate in a specific frequency band. See, for example, Smith, column 2, lines 42-44 and 63-65, and column 3, lines 1-3 (apertures in a given triplate have same size and shape), column 6, lines 8-12 (different triplates have different-sized apertures and operate in different frequency bands), and column 6, lines 16-20 (for a given triplate, the apertures are preferably sized at about one-half the operating wavelength).

Thus, Smith teaches away from the feature of the present invention that calls for substantially different aperture sizes in adjacent plates.

Accordingly, Applicants respectfully submit that claim 1 as currently amended is neither anticipated by Smith under 35 USC 102, nor obvious over Smith under 35 USC 103. For substantially the same reasons as set out above, Applicants submit further that claims 2 as depending from claim 1, and claim 10, as incorporating the limitations of claim 1, are likewise novel and non-obvious over Smith.

Claim Rejections under 35 USC 103

Claim 8 stands rejected as obvious over Rammos in view of Hall, U.S. Patent No. 4684953 ("Hall"). Hall is cited as providing the feature of a vertical radiator as recited in claim 8. Applicants respectfully traverse this rejection for the reasons set out below.

As noted, claim 1 as amended includes the limitation that at least two mutually aligned apertures lying in adjacent plates must differ in diameter by at least a factor of two. Claim 8, as depending from claim 1, also includes such a limitation. As argued above, Rammos neither teaches nor suggests any such limitation. Hall is directed to an antenna element in which a slotted plate overlies an unperforated plate. Thus, Hall also fails to teach or suggest mutually aligned apertures of substantially different sizes.

Accordingly, Applicants respectfully submit that claim 8, as amended, is patentable over Rammos and Hall under the standard of 35 USC 103.

Conclusion

All points of objection and rejection having been responded to, Applicants respectfully solicit withdrawal of the rejections and allowance of all claims now pending in the application.

Respectfully submitted,

Georg Fischer
Florian Pivit

By Finston

Martin I. Finston, Attorney
Reg. No. 31613
908-582-2908.

Attachments
10 Sheets Drawings
Appendix

Date: June 30, 2005

Docket Administrator (Room 3J-219)
Lucent Technologies Inc.
101 Crawfords Corner Road
Holmdel, NJ 07733-3030

OIPE
JUL 05 2005
PATENT & TRADEMARK OFFICE

APPENDIX

EP 0 252 779 B1

DESCRIPTION

The invention relates to a planar microwave antenna as indicated in the introduction to the principal claim. Such an antenna is known from European Patent Application EP-A-0123350.

It is known that the market for microwave antennas, in particular those operating in the S or X bands, needs to develop in a significant way, this because, among other things, of the many projects for transmitting satellite television programs. However, until now, network antennas likely to be used for the reception of such transmissions were designed using criteria of maximum efficiency, using sophisticated realizations not very compatible with mass production at reduced cost.

Thus, the antenna described in the French patent application 81 08 780 of May 4, 1981 (LEP) concerns an antenna of the "stripline" type intended to function in circular polarization, and presents the disadvantage of implying the use of an expensive solid dielectric material.

In addition, if one wishes to function in double polarization, the former device described proposes realizing two separate feed lines located in the same plane. However, such a feeder system is not possible when the planar network is not made up of a small number of elements. There is indeed a geometrical incompatibility in realizing such a network when for example it must consist of sixteen elements over sixteen, owing to the fact that some of the lines must cross each other.

The system described is thus relatively expensive and incapable in principle of being used for the realization of a network for a DBS satellite (telecommunications satellite for broadcasting or remote transmission), which usually comprises systems of 500 to 1000 elements.

Moreover, for a number of reasons, related in particular to the multiplicity of the parameters and the complexity of the phenomena intervening at the time of the development of the antenna network, specialists in these antennas have until now systematically imposed very strict conditions of tolerance for constructing and assembling the various elements of the antenna networks (conducting circuits, ground plates, dielectric materials, wave guides, etc). This prudence, or more precisely this prejudice, was particularly widespread with regard to the realization of microstrip antennas with suspended conductor, as attested to in the article "Multi-Conductor Guides" of the work "The Techniques of the Engineer" (E621-10). A recent attempt to be freed from the constraints of tolerance is exposed in Patent Application 83 06 650 of April 22, 1983 (LEP), which describes a microstrip suspended by positioning studs between two metal plates. These metal plates are machined in order to form waveguides coupled to terminations of the central conductor. However, the modes of realization described in the above patent always imply a machining operation in a thick metal plate (about 7 to 10 mm at 12 GHz).

To summarize the state of mind of the expert as regards microwave antennas, it has seemed unthinkable so far to produce a microwave antenna network by suspending a conducting circuit between two stamped plates as described hereafter. However, contrary to all expectations, the efficiency and the output of such an apparently rudimentary antenna are not only surprising, but also not very sensitive to the inaccuracies of working and assembly inherent in a mass production process.

Consequently, the present invention proposes to produce an antenna network making it possible in particular to cure the disadvantages mentioned above of the known devices.

To this end, a first object of the invention is to produce an antenna network of simple construction, thanks to the novel provision of the feeder lines, and with low tolerance requirements.

A second object of the invention is to realize the radiating elements integrated into the structure of the feeder lines, also for reasons of simplicity of construction.

Another object of the invention is to produce such an antenna network which functions over a broad band, thanks to the grouping, by pairs (or by a larger number), of radiating slots coupled electromagnetically to the feeder lines.

A complementary object of the invention is to produce an antenna of high efficiency (due to a low loss feeder system), which can also function in double circular polarization.

The present invention also exposes several variants of a simple and inexpensive process for production of such antennas utilizing forming and assembly processes with less severe tolerances adapted to mass production.

Another object of the invention is to provide such manufacturing processes allowing a maximum standardization of the constituent elements of each antenna.

A complementary object of the invention is to provide assembly and manufacturing processes of several standardized antenna modules, with the goal of realizing significant radiating surfaces at a low cost price.

These objectives, as well as others which will appear subsequently, are attained by means of an antenna or antenna element of the type comprising a central conductor interposed between two ground planes, and interacting with circular slots suspended within the ground planes and aligned in pairs, characterized in that the said central conductor is a conductive microstrip carried by a dielectric support sheet suspended between the upper and lower ground planes, in that the aforementioned ground planes are realized as self-supporting metal plates, and in that the spacing between the suspended central conductor and the metal plates is maintained by means of spaced positioning studs.

This structure characterizing the antenna according to the invention then makes it possible to obtain operation over a broad band, in particular if the two cavities of the same pair do not have quite the same diameter, and if the triplate structure is surmounted by an also hollowed additional plate.

In any event, because of use of air as a dielectric and the spacing of the positioning studs, the sheet support of the microstrip can be realized in an inexpensive dielectric without disadvantage.

Advantageously, triplate structure A, formed of the aforementioned sheet support of the feeder circuit and the two metal plates is supplemented by a reflective lower plate, the aforementioned reflective lower plate being separated from triplate structure A at a distance roughly equivalent to a quarter wavelength.

Advantageously, the antenna also comprises cavities closed at the back and/or cavities open in the front, in alignment with at least some of the pairs of radiating slots, the aforementioned cavities being produced by manufacturing processes of low tolerance.

According to another essential characteristic, the adjacent input modules of a modular antenna assembly according to the invention interact with common inputs/outputs of the signal in the form of low loss waveguides.

The objectives of the invention are also achieved using a manufacturing process of the antennas characterized in that the production of each one of the aforesaid ground plates is realized by a die stamping/embossing operation for, on one hand, cutting out the aforementioned radiating slots, and on the other hand for extruding the spacer studs on the faces of the plates turned towards the dielectric supporting the central conductor, in that the said antenna is assembled while simply having the nonconducting zones of the dielectric plate support of the printed conductor rest against the extrusions formed on the faces of the lower and upper ground plates so as to make the terminations of the conducting circuit jut out between the pairs of aligned slots, and in superimposing by bracing said triplate thus realized above a metal base plate located at the back of the antenna, and in that [the elements] are immobilized with respect to each other and the metal base plate and the elements of the aforesaid triplate thus assembled are made solid by a fixing means.

According to a significant characteristic of the invention, the process includes a cavity fabrication stage, and a stage of assembly of each cavity to the back of the antenna in correspondence with a pair of radiating slots.

In an advantageous way, one realizes the aforementioned cavities in particular by a die stamping/embossing operation of a metal plate, or by construction of a grid formed of an intersection of strips on edge defining between them rectangular cells closed by a bottom plate, or by assembly of truncated cylinders on the bottom plate, or finally by installation of a metal lining against the walls of cells formed in a block of nonmetallic material.

These various manufacturing processes constitute many inexpensive easy to implement alternatives, conferring in a surprising way a precision of fabrication and acceptable mounting.

According to an advantageous mode of realization of the process according to the invention, the means of fixing the elements of the antenna ensuring their relative immobilization and their staying solid comprises a set of fastening bolts of the unit, or again by a case to receive the superimposed elements of the antenna, the raised edges of which form a unit with the bottom plate of the antenna.

According to another advantageous characteristic of the invention, the process includes a stage of manufacture of an additional coupling crown [or, "ring" – Translator] made up of bottomless cavities realized in particular in a way similar to the closed cavities located at the back of the antenna, and a stage of assembly of the said crown on the radiating face of the antenna, in order to align each bottomless cavity with a pair of radiating slots.

The process according to the invention also includes a stage of assembly of several antenna modules manufactured according to one of the preceding methods, in which one juxtaposes several ground plate elements, and possibly several elements of back cavities and/or front crowns, to couple with a single conducting circuit. This manufacturing process, by decreasing the dimensions of the metal elements to be formed, and allowing their standardization, makes it possible to reduce still more the cost of the antenna. In this respect, the modularity of the antenna is particularly advantageous for the application of reception of television broadcasts by satellites, for which the receiving surface approaches for example 0.3 m^2 (individual antenna), as presented hereafter.

According to another principle of the modular antenna according to the invention, each module consists of an independent conducting circuit interacting with specific ground plates, back cavities and front crowns. The procedure for coupling of the modules for example is then characterized in that one realizes the input/output of the antenna as a waveguide, either by coupling the conducting circuits of at least two modules per connection as a "T" with single termination on a common waveguide, or by realizing separately the input/output of each module on independent waveguides coupled by power divider(s) in wave guide(s).

The standardization of manufacture of the modular conducting circuits is advantageously obtained when the manufacturing process of the antennas consists in using identical conducting circuit support plates for each module, the support plates being alternately turned to the front and to the back upon insertion between the embossed ground plates of adjacent modules.

Other characteristics and advantages of the invention will appear with the reading of the following description of preferred modes of realization of the invention, given on a purely illustrative basis and nonrestrictive, and of the annexed drawings in which:

- Figure 1 represents a exploded view of the basic version of the antenna according to the invention;
- Figure 2 represents a detailed cross sectional perspective view of two radiating elements of the antenna of figure 1;
- Figure 3 represents a T divider of the feeder line of the antenna according to the invention;
- Figures 4a, 4b and 5 represent theoretical plots of the impedance and the loss of the antenna according to the invention as a function of the distance between the plates containing the radiating slots and which form the ground planes of the feeder lines, and as a function of the centering of the feeder circuit in the case of typical operation in S band and/or X band of the prototype of Figure 22;
- Figure 6 represents a second mode of realization of the antenna according to the invention permitting double linear polarization;

- Figures 7 and 8 schematize two versions of the antenna according to the invention respectively comprising an additional electromagnetic coupling patch, and an additional of electromagnetic coupling slot;
- Figure 9 represents a mode of realization of the antenna according to the invention whose feeder circuit is made of a reversed printed circuit;
- Figure 10 is a transverse schematic section of a portion of an antenna module according to the invention, with ground plates, back cavities and front crowns before embossing;
- Figure 11 represents an exploded view of an antenna module according to the invention in which all the plates are realized by stamping;
- Figure 11b illustrates an alternative of realization of the cavities in the form of pressed caps;
- Figure 12 represents a module of antenna according to the invention with ring cavities;
- Figures 13a and 13b represent an antenna module according to the invention, with cavities defined by a grid of intersection of strips on edge;
- Figure 14 schematizes a module of antenna according to the invention with nonmetallic blocks pierced with cavities that are internally metallized;
- Figure 15 represents an assembly of several coupling plate modules according to the invention with a single conducting circuit;
- Figures 16, 17 and 18 represent examples of realization of the conducting circuit in the case of the single circuit of Figure 15 (Figure 16) and in the case of the juxtaposition of two conducting circuits of two adjacent modules (Figures 17 and 18);
- Figures 19, 20, 21 represent three processes of recombination of the output signal (or division of the input signal), in waveguides, for two adjacent antenna modules;
- Figure 22 represents an antenna element according to the invention realized to test its operating conditions;
- Figures 23a and 23b represent the results of measurements carried out on the antenna elements of Figure 22, and correspond respectively to measurement of the SWR [TOS in French – Translator], and the radiation diagram to 10 GHz in the plane H, in nominal polarization and cross polarization;
- Figure 24 represents the typical geometry of the conducting circuit of a module of antenna with 16 elements according to the invention realized to carry out the tests of operation;
- Figures 25a, 25b and 25c represent the results of measurement of tests carried out on the antenna module with 16 elements corresponding to the design of the central conductor of Figure 24, and correspond respectively to measurements of gain, SWR, and the determination of the radiation diagram in nominal polarization and crossed polarization in the plane H to 11 GHz.

As represented in Figures 1, 2 and 10, the antenna according to the invention is of the suspended microstrip type, made up of a central conductor 22 carried by a dielectric support sheet 12 suspended between two metal plates -- upper 11 and lower 13. Plates 11 and 13 are each provided with cavities 20a and 20b aligned pairwise on the level of projecting terminations 30 of the conductor 22. The structure of the antenna is also supplemented by a reflective metal bottom plate 14.

The relative positioning of planes 11, 12, 13, 14, the dimensioning of the cavities 20a, 20b, and length L of the projecting termination 30 of the conductor 22 are selected so that the cavities 20a, 20b play the role of electromagnetically coupled radiating slots, for a relatively broad frequency band of operation.

The cavities 20a, 20b of the same pair have their centers aligned on a vertical axis, and can have equal diameters. However, it is preferable that the diameters of the cavities of the same pair are slightly different so as to improve the bandwidth.

In fact, the frequency of operation of each cavity depends primarily on its dimensions, and if the two cavities of the same pair have a slightly different center frequency of operation, the total bandwidth is increased. The diameter of the cavities is about 0.3 to 0.7 wavelengths.

Advantageously, the spacing between two consecutive cavities on a line or a column can be equal to 0.7 to 0.9 wavelengths. The reflective bottom plate 14 makes it possible to give a direction to the radiated energy, and is at a distance from triplate structure A of the order of a quarter wavelength. The distance between this bottom reflective plate and the triplate structure is very significant because it gives the possibility of jointly optimizing operation with dimensions of the feeder line 22.

Figure 10 represents another mode of realization of an antenna mode according to the present invention, made up of the successive stacking of an embossed bottom plate 14 forming the closed cavities 26, of a lower embossed ground plate 13, of a support plate 12 of the conducting circuit 22 and of an upper embossed ground sheet 11 and of an embossed upper crown 25 forming the open cavities 27.

It should be noted that this mode of realization of the antenna exclusively utilizes a technology of metal sheet stamping [lit., "embossing" – Translator] for the manufacture of four plates 11, 13, 14, 25. The operation of stamping makes it possible on the one hand to release [produce?] the cavities 20a, 20b forming each radiating pair, and to form bulges or stops 31 which are positioning studs. These bulges 31 come to press against the dielectric intermediate plate 12, and define the spacing between the three plates of structure A. One thus obtains a feeder circuit of the "suspended" type, while realizing the radiating elements themselves. This type of antenna is thus particularly appropriate to mass production, because of reduced cost.

It should also be noted that the embossed plate 25 can also be placed inversely (meaning above / below) compared to its position in Figure 10).

Figure 10 does not take into account in any way the proportion of spacings and thicknesses of the plates. In fact, the distances H_U and H_L in particular were shown considerably oversize for reasons of clarity.

Of course, the two difficulties which arise in connection with an antenna with a suspended integral printed circuit, are on the one hand the conditions making it possible to have a good adaptation of each element at the operating frequencies and on the other hand the conditions guaranteeing a good efficiency of the antenna, i.e. an acceptable value of the gain per unit of area.

Surprisingly, technology used makes it possible to obtain, without difficulties, satisfactory values for these two parameters.

If one considers a radiating element of the antenna, comprising a conducting termination 30 connected to a pair of slots 20a, 20b and with a closed lower cavity 26, the adaptation of this element is a function of the length L of penetration of termination 30 between the slots 20a, 20b, of the distance d_f between triplate 11, 12, 13 and the bottom of cavity 26, diameter D_c of the cavity, the diameter D_e of the slots 20a, 20b, and the impedance Z_0 of the feeder conductor. In its turn Z_0 depends on the width W of the central conductor, the thickness H of the dielectric plate 12, and of distances H_U and H_L separating the electrical support plate 12 and upper and lower ground plates 11 and 13 respectively, as well as the dielectric constant epsilonR of the support plate 12.

These various factors influencing the adaptation of the antenna have an unequal relative importance. In particular, the distance d_f separating the triplate and the bottom plate (or the bottom of the closed cavity 26), as well as the relative positioning of the conductor 22 between the ground plates 11, 13, have a certain range of variations inside which the adaptation is not affected much. Thus, Figure 5 represents the calculations carried out on a line of the antenna (by the "Supercompact" program of C.A.O.), in which one moved the central conductor between the two ground plates while maintaining constant the distance b separating the ground plates. The dimensional specifications of the studied radiating element are as follows (referring to the notation of Figure 10):

w = 1.2 mm
$H_U + H_L$ = 1.6 mm
H = 0.075 mm
epsilonR = 2.2
f = 12.1 GHz.

It is perceived that the obtained variation of impedance Z_0 varies only by approximately 10% when one moves the conducting circuit in an interval centered between the ground planes 11, 13 and corresponding to a third of the spacing b between the two ground planes. This curve is one of the elements showing the low sensitivity of the claimed antenna to inaccuracies of manufacture and assembly, and thus the perfect feasibility of the invention.

These theoretical results are corroborated by the experimental measurements taken on a prototype.

As is seen in Figures 4a and 4b, the distance b separating the ground planes 11 and 13 is not very critical either for the resultant impedance of the system, whether for S band or X band.

The second significant parameter is the efficiency of the antenna, i.e. its gain per unit of area. In a surprising way, and as confirmed by measurements taken on a prototype and presented hereafter, the claimed antenna presents an about constant gain over a very significant bandwidth (12.5% on the prototype with 4x4 elements). However, for usable satellite reception in Europe a bandwidth of only about 7% (from 11.7 to 12.5 GHz) is required. Consequently, there is a comfortable margin of adaptation of the antenna, which easily tolerates the inaccuracies of fabrication and assembly due to the simplicity of the technologies of manufacture employed for the invention.

The efficiency of the antenna is moreover increased by limiting the losses in each radiating element.

The claimed technology lends itself perfectly to optimization in this domain. Indeed, the fact of using an air-like dielectric between the support plate 12 and the two ground planes 11, 13 makes it possible to reduce the losses compared to an equivalent antenna of the type "stripline" or "microstrip", where the central conductor is separated from two ground planes or a single ground plane respectively, by an expensive dielectric solid material. According to the invention, the dielectric of the support plate can be as thin as possible without harming its mechanical stability. As an example, it is noted that a thickness of 25 to 75 microns is perfectly appropriate. The losses as they are presented in Figures 4a and 4b for operation in S band (2.0 GHz) and X band (12.1 GHz) are thoroughly reduced due to the fact that there is no parasitic radiation because of the insulation of the circuit 22. (The graphs of loss in the Figures 4a, 4b correspond to the use of a dielectric with low loss tangent (tan d = 0.0009)).

The concentration of several elements on the same surface, with the aim of increasing the gain of the antenna, is realizable in the limit where the coupling occurring between each adjacent line does not exceed a certain limit that can be predetermined. However, the use of radiating slots on the one hand, and the care taken to the geometrical design of the conductor on the other hand, confer on the invention good performance from this point of view.

The use of pairs of radiating slots 20a, 20b causes the radiated energy to concentrate in a zone lower for example than that obtained in modes of realization where each conducting termination 30 is only coupled with cavities forming waveguides. Indeed, the width of a waveguide D_L is higher than the width D_e of the radiating slots. Because of the localization of the radiating effect caused by the radiating slots, the distance between two adjacent elements (for example element A and the element B of the antenna module of Figure 10) can be reduced to the lowest value that produces a tolerable value of decoupling between lines.

Moreover, to limit the influence of the positioning studs 31 on the adjacent elements or lines, one can reduce their number to a minimum and place them in planes shifted with respect to the slots, as represented of Figure 1.

The geometry of the lines also takes on a cardinal importance. An example of realization of the feeder circuit 22 is represented in Figure 3.

The impedance of the feeder circuit 22 depends on the width which it has at each of its conducting portions, for a given distance b between plates 11 and 13. The power dividers of the circuit 22, as represented of Figure 3, can be easily realized so as to obtain that the two uncoupled exits 41, 43 are adapted. This is carried out if the ratio of power emitted by the two exits 41, 43 is equal to or close to unity. It is then not necessary to envisage a fourth exit (for example in the form of a Wilkinson resistance bridged between the two uncoupled exits).

The power divider of Figure 3 is for example of the type with two adapted quarter wavelength exit sections 44, 45, with a gate width W producing an impedance Z_0 and a width W' of the said sections having a characteristic impedance equal to $2^{1/2}$ Z_0.

Figures 16, 17, 18 present modes of realization optimized for modules of 16 x 16 elements (two adjacent modules are represented in each Figure). Each mode of realization represented is particularly advantageous insofar as each of the 512 elements of the antenna has exactly the same electrical distance from the input/output of the antenna, and the obtained design releases, on the support plate of the conductor, the nonconducting zones 90 where, with no inconvenience, the embossed positioning studs 31 of the ground planes can rest.

The addition of a closed back cavity 26, and possibly of an open front cavity 27, to an antenna element makes it possible to collect the maximum of energy radiated in the transmission/reception direction of the antenna.

The polarization of the antenna according to the invention depends on the polarization of each radiating element.

If only one excitation line is used, the polarization is linear with an electric field E parallel to the excitation line.

Circular polarization can be obtained by using a printed plane polarizer (for example a polarizer with lines in loops) placed above the triplate.

Another way to acquire circular polarization consists in exciting two perpendicular linear polarizations in each radiating element.

Figure 6 represents a mode of realization of the invention, in which the two independent feeder lines being used for the excitation of each radiating element of the network are on two different levels 51, 52.

Consequently, structure A of the antenna is made up of five superimposed plates, namely three metallized plates 53, 54, 55 pierced with aligned cavities 20A, 20B, 20C, between which are inserted dielectric sheets 51, 52 carrying the feeder circuits 56, 57.

The excitation in "vertical" polarization for example is provided by circuit 56, and "horizontal" polarization is provided by circuit 57.

However, although this structure with five plates is justified in the case of a network with many radiating elements, it is also possible to form two circuits 56, 57 on the same dielectric plate, between only two metallized plates with cavities.

In the mode of realization of Figure 6, the median ground plate 54 is used by two circuits 56, 57. Preferably, the two external cavities 20a, 20c have the same diameter. The adaptation of each excitation line is obtained by adjusting the length of their termination that projects out with respect to the said cavities, and the distance to the reflective bottom plate 58. By applying a phase shift to the excitation lines of +90° or -90°, one can obtain a right or left circular polarization. If one uses a - 3dB hybrid to combine the signals coming from the two linear polarization exits, one can obtain a double circular polarization.

The modes of realization represented in Figures 7 and 8 present variants of the antenna represented of Figure 1.

The suspended triplate A of Figure 7 is surmounted by an additional coupling component 60. In the case of Figure 8, triplate A is surmounted by an additional plate 70 equipped with a cavity 71 appreciably in alignment with the cavities 20a, 20b.

In this latter case, the additional plate 71 can also be die stamped, and be separated from triplate A by dielectric spacers 72 or by studs formed by stamping.

These two modes of realization of Figures 7 and 8 make it possible to increase the bandwidth, that of Figure 8 being probably better from an electrical point of view.

It should be noted that for all the modes of realization represented, it is possible to increase the mechanical rigidity of the antenna assembly by, for example, replacing the air dielectric between the plates of structure A, or between this structure A and the bottom plate B, with a honeycomb dielectric inserted between the plates.

For reasons of compactness and simplicity of structure, it is also possible that the dielectric plate 12 bearing the feeder circuit 22 is not between the two metallized plates 11, 13. This mode of realization is realized in Figure 9. The antenna network then consists of a succession of plates in an order different from that of Figure 1, the higher plate 11 and the lower plate 13 being separated by a spacer 80. The dielectric plate 12 bearing the circuit 22 is then coupled outside the double plate thus formed, on the side of the bottom plate 14. In an advantageous way, the feeder circuit 22 is in the form of an inverted reversed printed circuit. In any event, dielectric plate 12 prevents any contact between the circuit 22 and the metallized plate 13.

Figures 11, 12, 13, and 14 illustrate four technologies for manufacturing the front and back cavities, for an antenna module with embossed ground planes 11, 13. More precisely, Figure 11 is an exploded view of an antenna module with 4 x 4 elements of the type represented in Figure 10. The module is simply constituted of a stack of embossed plates 14, 13, 11, 25, within which the support plate 12 of the conducting circuit 22 is placed.

In an advantageous manner, by adding embossed positioning studs in plate 14 and plate 25, positioned inversely, plates 11 and 13 can be removed.

The stack thus produced can be maintained in place either using bolts 26 going through all the plates (Figure 2), or by realizing the bottom plate 14 in the form of a case. The stack can either be fitted onto the case, or introduced at least partially inside the case. In all the cases, it is necessary to obtain a predetermined spacing d_f between the triplate and the bottom of the case. The case can be deep drawn or machined by any other means, or even realized by metallization of a nonmetal case. The fixing and the clamping of the assembly are carried out by screwing, joining, soldering, etc.

Of course, the mode of realization of the invention represented on Figure 11 can, if necessary, be realized with a planar bottom plate 14, possibly forming a support case, and maintained at a distance from triplate 11, 12, 13. The crown 25 with open cavities 27 is optional. If one uses closed rear cavities, a nonmetallic support case B (for example: out of plastic) can be used.

The rear closed cavities 26 can also tale the form of individual pressed caps 72 (Figure 11b) and be connected by soldering, gluing etc, to the lower ground plate 13, with respect to the pairs of radiating slots.

Figure 12 represents another mode of realization of an antenna module according to the invention in which the rear closed cavities 26, and the front cavities 27 are realized by metal rings 150, mounted by any means on the complete bottom plate 14, and an added plate 151 respectively. In an advantageous way, the fixing of rings 150 on the metal bottom plate 14 is realized by soldering, gluing or the equivalent. The added plate 151 may or may not be metal, and rings 150 can be also glued or otherwise [attached] to plates 14 and 151.

In a mode of realization slightly different from that of Figure 12, but always using metal rings, the case B is used to hold an ensemble of cylindrical metal rings 150 on which will come to rest the triplate 11, 12, 13. Plates 14 and 25 became useless. Rings 150 are mounted by any means on the bottom of the case and/or the lower ground plate 13.

Advantageously, the fixing of rings 150 to the metal plate or metallized bottom of the case and/or to the ground plate 13 is realized by soldering, gluing, or the equivalent.

In the mode of realization of Figures 13A and 13B, the case B is used as housing of a set of interlaced strips 160 placed on edge, and forming a grid on which the triplate the 11, 12, 13 will rest. In an advantageous way, the grid is made of strips provided with notches 161, designed to interlock with one another as depicted in Figure 13B.

The intersection of the strips defines cavities 162 each corresponding to one of the radiating elements of the triplate. One can note in this respect that the shape of the cavities of the antenna module is not a restrictive characteristic of the invention, nor is the shape of the radiating slots 20a, 20b. Circular, square, elliptic, rectangular, and polygonal cross sections as necessary can be appropriate. In this respect, one will be able to note that in certain cases, rectangular openings are interesting in that they make available more space for the conductor 22.

Figure 14 illustrates a fourth mode of realization of the invention, according to which the rear closed cavities 26 are realized by placing a metal coating on the walls of a cavity 170 cut into, but not cut all the way through, a nonmetallic base block 171. As a nonrestrictive example, the base block can be made out of plastic, and the metallization of the cavities can be realized by means of aluminum foil. In the case of a base block not cut all the way through, the case support B of Figure 14 can be removed. The base block can also be replaced by a juxtaposition of elementary blocks, each having one or more cavities. If the cavities are cut through, the metallic bottom metal plate closes the cavities.

It is understood that the modes of realization of Figures 11 to 14 can be combined and in particular that the antenna modules of Figures 13 and 14 can be provided with a front crown of the embossed plate type, or with rings 150. The addition of open front cavities 27 makes it possible to increase the gain of the antenna. The cavity height is preferably greater than 0.1 times the emission wavelength. As an example, a height for the open cavities of 5 mm to 10 mm would yield an increase in gain of about 2 dB depending on the geometry, for an operating frequency of 12 GHz.

Whatever the means used for the relative immobilization and the rigidization of the plates of the various modes of realization of the antenna module according to the invention (fastening bolts, case B or others), the modules can then be coated with an electromagnetically neutral material such as expanded or molded plastic, for example with expanded polyurethane. This coating has in particular the advantage of protecting the module against bad weather when the antenna must be used outside.

In an advantageous way, an antenna can be produced by combination of several modules. In the case of antennas of relatively large size, this technique has the advantage of reducing the manufacturing cost, by decreasing the size of the tools used. In the mode of realization using embossed plates, the savings realized can be significant; moreover the reduction in the size of the tools makes it possible to better control the manufacturing precision of the embossed plates.

Moreover, the advantage even more considerable if each antenna is produced by addition of several identical modules, as will be presented below.

Figure 15 presents a first mode of realization of a modular antenna, in which the single conducting circuit 80 covers two modules 81, 82 realized according to any of the modes of realization described previously. More precisely, the left part of the support plate 80 is inserted for example between an upper ground plate 11A, and a lower ground plate 13a mounted in a case Ba as regards the first module 81, and between corresponding components 11b, 13b, Bb as regards the second module 82.

The conducting circuit 80 is for example of the type represented of Figure 16.

This mode of realization is relatively satisfactory, but presents the disadvantage that input/output section 83 of the antenna conductor runs along the intersection of the modules. To avoid possible unfavorable effects caused by the slot effect due to imperfect joining of the plates of the modules, because of technology chosen, one can close that joint with a thin metal sheeting, for example of self-adhesive copper or something else.

However, it is more satisfactory, in order to mitigate this possible disadvantage, to realize the conducting circuit itself in two parts. Modes of advantageous realization of the conducting circuit in two parts are represented in Figure 17 (vertical polarization) and 18 (horizontal polarization). It will be noted that, in the two modes of realization, the two adjacent circuits are identical and allow a standardization of their production.

In these Figures 17 and 18, conductor 83 is thus realized in the form of two decoupled parallel lines, on both sides of the plane joining two adjacent antenna modules. In these modes of realization, each antenna element is at an identical electrical distance from the point of input/output of the conducting circuit.

In Figure 18, the two modules comprise identical conducting circuits oriented in the same direction (without having symmetry with respect to the line of junction). In an advantageous way (not represented), the feeder sections 110 skirt the totality of the appropriate edge of the support plates 22a, 22b in order to standardize their manufacture; in this case, the parasitic half-sections are disconnected by notching over all their width, preferably at 45°, to the level of their connection with the vertical lines.

The input/output of the adjacent modules is realized preferentially as waveguides as represented in figure 19 or 20. The use of a direct waveguide exit is advantageous compared to the use of a coaxial [design] which constitutes a more expensive solution. Figure 19 illustrates a input/output waveguide if the two adjacent conducting circuits are electrically connected by a T divider to present a single termination 120. To this end, openings 121a, 121b, 122a, 122b are realized on the edges of junction of the upper plates 11a and 11b and lower plates 13a, 13b of adjacent modules. The pair of openings thus realized after joining the modules is supplemented by an upper cover 123 forming a closed waveguide element, and returning towards an of input/output waveguide 124 located on other side of the triplate.

The reflecting upper cover 123 is realized for example out of metallized plastic or pressed sheet metal. Its height is for example on the order of a quarter wavelength.

In order to limit the effect of the junction slot, and to improve the electrical connection of the adjacent plates 11a, 11b and 13a, 13b respectively, it is possible to place thin metal sheets 125, 126 around each opening 121a, 121b, 122a, 122b, by gluing or other [methods].

The input/output waveguide 124 can for example be screwed, glued or otherwise [attached] to the lower metal ground 13a, 13b.

This mode of realization is appropriate for the case of a single printed circuit cooperating with two modules (case of Figure 15) as well as for the case of two distinct modules, whose respective conducting circuits only are later on connected electrically on a single termination.

The electrical connection of the two conductors can for example be realized as represented in Figure 21, or the two support plates 12a, 12b of the adjacent modules can overlap at their junction, such a manner as to overlap the input/output terminations of their respective conducting circuits 22a, 22b.

In a mode of advantageous realization of the invention, and as represented of Figure 17, the conducting circuits 22a, 22b of two adjacent modules are realized starting from two identical printed circuit support plates, of which one is employed [aligned] to the front, and the other to the back. In this case, the printed circuit of one of the support plates is on the upper face, whereas the other printed circuit is on the lower face. The slight shift which results from it does not present however any disadvantage, since we have noted above the low sensitivity of the impedance Z_0 of the antenna according to the invention, and thus of its adaptation to minor variations of position of the printed circuit between the two ground planes. However, the dielectric material plate support which carries the printed conducting circuit 22a, 22b can be very thin, for example about 50 microns.

If the two adjacent circuits are reversed compared to one another, the electrical connection of Figure 21 can be realized by drilling right through the support plates 12a, 12b on the level of the input/output terminations 140a, 140b of the corresponding conducting circuits, then soldering the circuits through the aforementioned drilled holes.

Figure 20 represents another mode of realization of the combined input/output device of the conducting circuits of two adjacent modules. In this case, no electrical connection is realized, and the combination is realized through a power divider 130, out of bent waveguide, so as to return the signal along the bottom of the antenna.

Each adjacent triplate is then equipped with a pair of exit slots (131a, 131b), over which is placed a double closed cover 132.

Advantageously, the double cover 132, as well as the simple cover 123 of Figure 19 can be realized at least partially by stamping the upper plates 11a, 11b of the adjacent modules of the antenna.

Lastly, it is always possible to stabilize the support plates 12a, 12b of two adjacent modules by applying an adhesive tape, preferably nonmetallic, to the adjacent edges of the support plates, in particular along their free half-depth of the central conductor.

The parasitic coupling of the two adjacent modules can also effectively be avoided by arranging between the modules an interval [a space?] greater than a wavelength between the radiating elements (84, 85), close to both modules (81, 82). This free interval advantageously allows the passage of the central feeder conductors, eliminating the risks from coupling and without affecting the radiation diagram too significantly.

EXAMPLE OF REALIZATION

Tests were carried out on an antenna module made of only one element as represented in Figure 22 with the goal of determining the bandwidth obtainable with the implementation of the invention.

The test element is formed of two aluminum plates of 0.8 millimeter thickness, forming the ground plates 11, 13. Each plate has a radiating opening of 16.5 mm. The distance between the ground plates 11, 13 is 1.7 mm. A thin sheet of "Kapton", 75 microns thick, supports the printed central conductor 22. The width of the central conductor corresponds to a line impedance $Z_0 = 50$ ohms for a ground plates 11, 13 spacing of 1.7 mm.

The excitation termination 30 of the conductor penetrates 5.0 mm between the slots 20a, 20b. Lastly, a closed cylindrical cavity 26 with a diameter 20 mm and height 9.2 mm was aligned under the pair of radiating slots 20a, 20b. This demonstration element is optimized to function around frequencies close to 11 GHz. The manufacturing tolerances of this element were voluntarily maintained to be very coarse. To this end, three successive tests were carried out.

For the first test, on the one hand, the SWR was measured over the band 10.4 GHz - 12.4 GHz for a standard conductor fabricated using lithography. Figure 23a reproduces the measurements obtained, which show a remarkable behavior of the element presenting a SWR lower than 1.4 over a bandwidth greater than 20%.

In addition, Figure 23b shows that measured cross polarization is very low (lower than -30 dB) in the direction perpendicular to the plane of the elementary antenna. The useful radiation of the element is realized in linear polarization with an electric field parallel to the line of excitation. The second test carried out on the element consisted in replacing the excitation conductor 22 manufactured by lithography with a conductor cut out by hand (with a scalpel) for an impedance of 75 ohms from a 50 ohm line. The measurement of the SWR did not show a difference compared to the standard line realized by lithography.

In the third test carried out on the radiating element of Figure 22, the cylindrical cavities 26 were replaced by a cavity realized with kitchen aluminum foil. The tests carried out did not show a notable increase in the SWR. The antenna specialists of the Dutch laboratory C.H.L. who made these measurements expressed their surprise regarding the quality of the test results obtained, since they were accustomed to work with precisions on the order of a micron.

A second series of tests was carried out on an antenna module with 16 elements, with a design of the conducting circuits as represented in Figure 24.

As it was not economic to realize the test model by stamping, truncated cylinders glued to form back closed cavities were utilized. The spacing studs 31 were not formed by embossing, but by gluing sheet contacts on the ground plates 11, 13.

Test measurements were also carried out in the anechoic chamber of the C.H.L. Laboratory. These measurements confirm the good results already noted during the test of the single antenna element, and besides, are of a nature more reliable than the preceding tests owing to the fact that a module of 16 elements is less sensitive to the conditions of measurement than a single element.

The graph 25a indicates that the maximum gain obtained is 20 dB, and that the gain is higher than 19 dB over a frequency band wider than 10% (from 10.25 to 11.5 GHz).

The measured SWR is lower than 2 over a frequency band of width larger than 2 GHz (Figure 25b).

Finally, the radiation diagram at 11 GHz of Figure 25c confirms the absence of cross polarization in the principal direction of radiation. The first lobes of cross polarization are at about -25 dB compared to the maximum principal radiation.

Consequently, the antenna modules according to the invention make it possible to obtain excellent performance with low tolerance manufacturing processes corresponding to low cost mass production.

In terms of preferred applications, the invention can be used to manufacture reception antennas of satellite television broadcasts in X band. Advantageously, these antennas consist of two formed adjacent modules each of 16 X 16 elements. This preferred application corresponds to the designs of the conducting circuit represented in Figures 16, 17, 18. In the most frequent case where the polarization of the emission is circular, it is possible either to lace a printed plane polarizer above the antenna, or to superimpose on the antenna an additional stage with excitation terminations perpendicular to the terminations 30 of the basic stage, as illustrated of Figure 6.

The frequency band of operation can for example be X band (3 cm), S band (1500 to 5200 MHz), or L band (390 to 1550 MHz). Although the antenna according to the invention can function also in theory in higher frequency bands, its structure makes it more advantageous for use at X band frequencies and lower, because the tolerance constraints are even less strict which make its fabrication even easier.